CLAIMS

What is claimed is:

1. A photovoltaic device, comprising:
a nanostructured template made from an n-type first charge transfer-material, the nanostructured template having template elements between about 1 nm and about 500 nm in diameter with a template element density of between about 10^{12} elements /m^2 and about 10^{16} elements /m^2;
a second charge-transfer material conformally coating one or more walls of the template elements leaving additional space, wherein the first charge-transfer material is n-type and the second charge-transfer is p-type; and
a third material in the additional space, wherein the third material is a p-type or conducting material that volumetrically interdigitates with the second charge-transfer material,
wherein a lowest unoccupied molecular orbital (LUMO) or conduction band of the first charge-transfer material differs from a LUMO or conduction band of the second charge-transfer material by less than about 1 eV, wherein a light absorbance of at least one charge transfer material is greater than about 10^3/cm at the peak of the absorption spectrum.

2. The device of claim 1 wherein the third charge-transfer material in the form of one or more elongated structures that volumetrically interdigitate with the second charge transfer material.

3. The device of claim 2, further comprising a base electrode and a top electrode, wherein the nanostructured template is disposed between the base electrode and top electrode.

4. The device of claim 3, wherein the first charge-transfer material is in electrical contact with the base electrode and the third charge-transfer material is in contact with the top electrode.

5. The device of claim 3, further comprising one or more plugs of material at the tips of the elongated structures, wherein the plugs protect against undesired electrical contact between the third charge-transfer material and the template and/or base electrode.

6. The device of claim 3 wherein the third charge-transfer material is a transparent conductive material.

7. The device of claim 3 wherein the third charge-transfer material includes an organic semiconducting material.

8. The device of claim 7 wherein the third charge transfer material has a different light absorption range and/or a different HOMO/LUMO level than the second charge transfer material.

9. The device of claim 2 wherein one or more of the base electrode and top is a transparent electrode.

10. The device of claim 1 wherein the first charge-transfer material is an inorganic material and the second and third charge-transfer materials are organic materials.

11. The device of claim 1 wherein the first charge-transfer material is an electrically semiconductive or conductive material.

12. The device of claim 1 wherein the second charge transfer material coats the template elements up to a level that is substantially even with an upper surface of the template.

13. The device of claim 1 wherein the first, second, or third charge-transfer material includes one or more materials from the group of titanium oxide, zinc oxide (ZnO), copper oxide, copper sulfide, zirconium oxide, lanthanum oxide, niobium oxide, tungsten oxide, tin oxide, indium tin oxide (ITO), strontium oxide, calcium/titanium oxide, indium oxide, vanadium oxide, zirconium oxide, molybdenum oxide, vanadium oxide, strontium oxide, sodium titanate, potassium

niobate, silicon, tungsten oxide, cadmium selenide (CdSe), zinc selenide (ZnSe), cadmium suflide (CdS), cadmium telluride (CdTe), cadmium selenide (CdSe), cadmium telluride selenide (CdTeSe), CIS, CISe, CIGS ($CuInGaSe_2$), copper-indium selenide, cadmium oxide, or blends or alloys of two or more of these materials.

14. The device of claim 1 wherein the first charge-transfer material includes a transparent conductive oxide.

15. The device of claim 15 wherein the first charge-transfer material includes titanium oxide or zinc oxide.

16. The device of claim 15, wherein the second charge-transfer material is a p-type semiconducting material.

17. The device of claim 1, further comprising an interfacial layer disposed between the first and second charge-transfer materials.

18. The device of claim 17 wherein the interfacial layer includes one or more materials chosen from the group of fullerenes, doped fullerenes, functionalized fullerenes, C_{60}-COOH, doped functionalized fullerenes, azafullerenes, polymerized fullerenes (doped or undoped), functionalized polymerized fullerenes (doped or undoped), phenyl-C_{61}-butyric acid methyl ester (PCBM), carbon nanotubes, dyes, ruthenium dyes, pigments, organic monomers, oligomers, and polymers, tetra-hydro-thiophene precursor polymers and derivatives thereof, poly-phenylene-vinylene and derivatives thereof, conjugated polymers, and/or blends of these materials.

19. The device of claim 17 wherein the interfacial layer includes one or more chemicals that can covalently attach to the first charge-transfer material and change a surface energy and/or bonding trap-states and/or attach to dangling-bonds at an exposed surface of the first charge-transfer material and/or introduce a dipole layer that may increase the efficiency for charge extraction and/or reduce detrimental charge recombination.

20. The device of claim 17 wherein the interfacial layer includes C_{60} or other fullerenes functionalized with a carboxylic acid moiety.

21. The device of claim 1 wherein the second charge-transfer material includes two or more complementary charge-transfer materials that are blended together.

22. The device of claim 1 wherein the second and third charge-transfer materials are both organic materials.

23. The device of claim 1 wherein the one or more of the second or third charge-transfer materials includes a material chosen from the group of thiophene-, fluorine- or aryl-vinyl- based polymers, copolymers or blends, poly(phenylene) and derivatives thereof, poly(phenylene vinylene) and derivatives thereof, poly(2-methoxy-5-(2-ethyl-hexyloxy)-1,4-phenylene vinylene (MEH-PPV), poly(para-phenylene vinylene), (PPV), PPV copolymers, poly(thiophene) and derivatives thereof, poly(3-octylthiophene-2,5,-diyl) regioregular, poly(3-octylthiophene-2,5,-diyl) regiorandom, poly (3-hexylthiophene) (P3HT), poly(3-hexylthiophene-2,5-diyl) regioregular, poly(3-hexylthiophene-2,5-diyl) regiorandom, poly(thienylenevinylene) and derivatives thereof, poly(isothianaphthene) and derivatives thereof, tetra-hydro-thiophene precursors and derivatives thereof, poly-phenylene-vinylene and derivatives, organometallic polymers, polymers containing perylene units, poly(squaraines) and their derivatives, discotic liquid crystals polyfluorenes, polyfluorene copolymers, polyfluorene-based copolymers and blends, polyfluorene-based copolymers co-polymerized and/or blended with charge transporting compounds , polyfluorene-based copolymers co-polymerized and/or blended with tri-phenyl-amines and/or derivatives, polyfluorene-based copolymers co-polymerized and/or blended with light-absorbing compounds, polyfluorene-based copolymers co-polymerized and/or blended with fused thiophene rings and derivatives or hetero-atom ring compounds with or without substituents, pigments, dyes, or fullerenes, and mixtures of these materials.

24. The device of claim 1, wherein one or more of the second and third charge-transfer material is a pigment, dye or small molecule chosen from the group of organic pigments or dyes, azo-dyes having azo chromofores (-N=N-) linking aromatic groups, phthalocyanines including metal-free phthalocyanine; (HPc), Zinc phthalocyanine (ZnPc), Copper phthalocyanine (CuPc), perylenes, naphthalocyanines, squaraines, merocyanines and their respective derivatives, poly(silanes), poly(germinates), 2,9-Di(pent-3-yl)-anthra[2,1,9-def:6,5,10-d'e'f']diisoquinoline-1,3,8,10-tetrone, and 2,9-Bis-(1-hexyl-hept-1-yl)-anthra[2,1,9-def:6,5,10-d'e'f']diisoquinoline-1,3,8,10-tetrone, pentacene and/or pentacene precursors, and mixtures of two or more of these materials.

25. The device of claim 1 wherein one or more of the second or third charge-transfer materials includes one or more materials chosen from the group of fullerenes, doped fullerenes, functionalized fullerenes, doped functionalized fullerenes, azafullerenes, polymerized fullerenes (doped or undoped), functionalized polymerized fullerenes (doped or undoped), carbon nanotubes, dyes, ruthenium dyes, pigments, organic monomers, oligomers, and polymers, tetra-hydro-thiophene precursor polymers and derivatives thereof, poly-phenylene-vinylene and derivatives thereof, conjugated polymers, and mixture of these materials.

26. The device of claim 1 wherein the template elements are in the form of hollow tubes that protrude from the template with spaces between the sidewalls of the tubes.

27. The device of claim 1 wherein the third charge transfer material includes one or more transparent conducting materials.

28. The device of claim 27 wherein the one or more transparent conducting materials include PEDOT, PEDOT doped with a dopant PEDOT doped with polystyrene sulfonic acid (PSS), doped 2,2'7,7'-tetrakis(N,N-di-p-methoxyphenyl-amine)-9,9'-spirobifluorene (doped *spiro-MeOTAD*), doped spiro-MeOTAD, polyaniline

doped with a dopant, and/or polyaniline doped with a dopant polystyrene sulfonic acid (PSS)).

29. The device of claim 27 wherein the one or more transparent conducting materials conformally coat and interdigitate into the second charge transfer material.

30. The device of claim 1 wherein the second and third charge-transfer materials are both inorganic materials.

31. The device of claim 1 wherein the second and third charge transfer materials are the same material.

32. A photovoltaic device, comprising:
a base electrode;
a top electrode;
a nanostructured template disposed between the base electrode and top electrode, wherein the nanostructured template in made of an n-type material, the nanostructured template having template elements between about 1 nm and about 500 nm in diameter with a template element density of between about 10^{12} elements /m^2 and about 10^{16} elements /m^2;
a p-type material coating on one or more walls of the template elements in a way that leaves additional space; and
a charge-transfer material in the additional space, wherein the charge-transfer material volumetrically interdigitates with the p-type material.

33. A method for making a photovoltaic device, comprising the steps of:
forming a nanostructured template from a first charge-transfer material, the nanostructured template having template elements between about 1 nm and about 500 nm in diameter with a template element density of between about 10^{12} elements /m^2 and about 10^{16} elements /m^2;
coating one or more walls of the template elements with a second charge-transfer material in a way that leaves additional space, wherein the second charge-transfer material has complementary charge-transfer properties with respect to the first

charge-transfer material; and

filling the additional space with a third charge-transfer material.

34. The method of claim 33 wherein the first charge-transfer material includes titanium oxide or zinc oxide.

35. The method of claim 33 wherein forming a nanostructured template includes anodizing a layer of metal.

36. The method of claim 33 further comprising disposing an interfacial layer between the second and third charge transfer materials.

37. The method of claim 33 wherein the third charge-transfer material includes one or more elongated structures that interdigitate with the second charge transfer material.

38. The method of claim 37 further comprising capping one or more tips of the elongated structures with a short-proofing material.

39. The method of claim 33 wherein coating one or more walls of the template elements with the second charge-transfer material includes depositing the second charge transfer material on the walls of the nanostructured template.

40. The method of claim 39 wherein depositing the second charge transfer material on the walls of the nanostructured template includes the use of a technique selected from the group of electrochemical deposition, electroless (chemical bath) deposition, layer-by-layer deposition, evaporation, sputtering, plating, ion-plating, molecular beam epitaxy, and sol-gel based deposition, spray pyrolysis, vapor-phase deposition, solvent vapor deposition, atomic layer deposition, plasma-enhanced atomic layer deposition, atomic vapor deposition, metal-organic vapor phase deposition, metal-organic-vapor-phase epitaxy, chemical vapor deposition, metal-organic chemical vapor deposition, plasma enhanced chemical vapor deposition, self-assembly, electro-static self-assembly, melt-filling/coating electro-deposition, electro-plating, ion-plating, or liquid phase deposition.

41. The method of claim 33 wherein filling the additional space with the third charge transfer material includes depositing the third charge transfer material by a technique selected from the group of electrochemical deposition, electroless (chemical bath) deposition, layer-by-layer deposition, evaporation, sputtering, plating, ion-plating, molecular beam epitaxy, and sol-gel based deposition, spray pyrolysis, vapor-phase deposition, solvent vapor deposition, atomic layer deposition, plasma-enhanced atomic layer deposition, atomic vapor deposition, metal-organic vapor phase deposition, metal-organic-vapor-phase epitaxy, chemical vapor deposition, metal-organic chemical vapor deposition, plasma enhanced chemical vapor deposition, self-assembly, electro-static self-assembly, melt-filling/coating electro-deposition, electro-plating, ion-plating, or liquid phase deposition.

42. The method of claim 33 wherein the third charge transfer material includes one or more transparent conducting materials.

43. The method of claim 42 wherein the one or more transparent conducting materials include PEDOT, PEDOT doped with a dopant PEDOT doped with polystyrene sulfonic acid (PSS), doped 2,2'7,7'-tetrakis(N,N-di-p-methoxyphenyl-amine)-9,9'-spirobifluorene (doped *spiro-MeOTAD*), doped spiro-MeOTAD, polyaniline doped with a dopant, and/or polyaniline doped with polystyrene sulfonic acid (PSS)).

44. The method of claim 42 wherein the one or more transparent conducting materials conformally coat and interdigitate into the second charge transfer material.

45. The method of claim 44 wherein the one or more transparent conducting materials include PEDOT, PEDOT doped with a dopant PEDOT doped with polystyrene sulfonic acid (PSS), doped 2,2'7,7'-tetrakis(N,N-di-p-methoxyphenyl-amine)-9,9'-spirobifluorene (doped *spiro-MeOTAD*), polyaniline doped with a dopant, and/or polyaniline doped with polystyrene sulfonic acid (PSS)).